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Tripping Profile Analysis of the 33 kV Feeder of Ugbowo 2 x 15 MVA, 33/11 kV Injection Substation

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Abstract
This paper investigated the tripping profile of the 33 kV feeder of Ugbowo 2 x 15 MVA, 33/11 kV electric power distribution network. The annual data of daily tripping of the 33 kV feeder from September 2019 to August 2020 were collated and collected from the Ugbowo injection substation. The daily outage of the 33 kV feeder was used to compute the monthly and yearly tripping profile of the sub-transmission line (33 kV feeder) of the Ugbowo injection substation. The monthly and yearly failure rate, MTTR, MTTF, MTBF, availability, unavailability, SAIFI, SAIDI, ASAI, ASUI, etc. for the period of twelve (12) months were analyzed using the Load Point Indices (LPI) and Microsoft Excel was used graphically to interpret the results of the tripping profile of the 33 kV feeder. The results obtained from the analyses of the 33 kV feeder of the network showed that yearly failure rate, MTTR, MTTF, MTBF, unavailability, availability, SAIFI, SAIDI, ASAI and ASUI were 4.32%, 6.520 h, 23.148 h, 29.668 h, 21.98%, 78.02%, 0.0358 interruptions/customer/yr, 0.2336 h/customer/yr, 78.03%, and 21.97%, respectively. These results revealed that the performance indices of the 33 kV feeder with annual total outage frequency (SAIFI) and percentage availability (ASAI) were a far cry from the recommended values of the internationally acceptable standard value (IASV) of 0.01 and 99.99% respectively. This poses a threat to the reliability and availability of electricity supply to consumers.

Keywords: Feeder, Failure rate, Performance index, Tripping profile, Unavailability

1. Introduction

The incessant power outage in the Ugbowo distribution network has become a recurrent decimal which needs to be nib at the board if blackout in the network will be reduced to barest minimum. Customer interruptions data showed that the distribution system failures are responsible for 80% of the consumer outages in power system [1]. According to Akpojedje *et al.* [2], the satisfaction and importance of availability of electricity supply to consumers at the time of usage cannot be overstretched. A reliable power supply enhances productivity and minimizes waste in any system. According to Akpojedje *et al.* [3], a reliable electricity supply is a foundation for ubiquitous usage of electricity by the consumers. The epileptic electricity supply in the network under study has become alarming and a source of concern to all stakeholders. According to Akpojedje and Ogujor [4], the need to assess the tripping profile of the feeders in the Ugbowo 2x15 MVA, 33/11 kV distribution network has become crucial owing to the fact that consumers complains arising from the frequent outages have become alarming. Sympathetic tripping of feeders is currently the biggest problem that has of late, plagued the power industry [5]. The assessment of the tripping profile of Oluku 33 kV feeder becomes crucial since its outage contributes to the unavailability of the Ugbowo 2x15 MVA, 33/11 kV injection substation. According to Idoniboyeobu *et al.* [6], it is pertinent to state categorically that reports have it that at different occasions, customers experience power outages due to tripping of the 33 kV feeder connected to the injection substations. The distribution network encompasses the injection substation which form the last part of the power systems that delivers electricity from generation to consumers via transmission and sub-transmission lines [7]. Reliability engineering is used to assess system performance, but with regards to distribution network it involves gathering of historical data and evaluating the data for the assessment of the performance of the system or its component [8].

Power outage describes the state of a system or component not being able to perform its intended function(s) due to some events that are directly or indirectly associated with the system or component [9]. Outages in the distribution networks are known for their localized effects and can be classified by the number of consumers affected and the duration of time the power supply is unavailable [10].

The major aim of the injection substation is to meet customers/users' demand for electric energy after receiving bulk electrical energy from the sub-transmission line (33 kV feeder) [10]. But if the 33 kV feeder outage become frequent, then the reliability and availability of electrical energy distributed to consumers by the injection substation will be affected. Distribution system outages have localized effects compared to generating station and transmission network outages that are system wide [2], but the sub-transmission line (33 kV feeder) outages affect several injection substations connected to the line. Frequent power cut has negative effect on economic growth and social development of any society [4]. According to Folarin *et al.* [9], reliability of electric power systems affects public health and safety, economic growth and development, as well as social well-being of the people. The frequent power cut of the 33 kV feeder is one of the major causes of poor performance of the distribution network. Thus, the tripping profile of the 33 kV feeder and its performance index assessment cannot be overstretched. Therefore, this paper presents an appraisal of the tripping profile of Oluku 33 kV feeder vis-à-vis its performance index assessment of the Ugbowo 2 x 15 MVA, 33/11 kV electric power distribution network.

2. Methodology

The research analysis carried out involves personal consultation and interview of energy consumers of the distribution network and the staff of Benin Electricity Distribution Company (BEDC) domicile at the Ugbowo 2x15 MVA, 33/11 kV injection substation. The data was collected for the period of twelve (12) months (September 2019 to August 2020) from the following materials of the injection substation:

i. Daily shift report logbook kept at the Ugbowo 2x15 MVA, 33/11 kV injection substation.
ii. Daily report logbook of faults recorded in the distribution network.
iii. Physical inspection of the recording meters of the 33/11 kV panels of the Ugbowo injection substation.

The daily power failure data of the 33 kV feeder (line) of the Ugbowo 2x15 MVA, 33/11 kV injection substation were collated from the substation logbooks using analytical method for the period under study. The tripping profile data of the 33 kV feeder connected to 2x15 MVA, 33/11 kV power transformers in the injection substation was collected and computed. The data collected from the injection substation logbooks were analyzed using Load Point Indices (LPI) to estimate the failure rate, mean time to repair or recover, failure mean time, mean time between failure, availability, unavailability, while the SAIFI, SAIDI, ASAI, ASUI, etc. were used to determine Performance Indices (PI) of the 33 kV feeder and the results obtained were interpreted graphically using Microsoft Excel.

2.1 Single Line Diagram of Ugbowo 2 X 15 MVA, 33/11 kV Injection Substation in ETAP Model

The single line diagram (SLD) of the Ugbowo 2x15 MVA, 33/11 kV distribution network modeled in Electrical Transient and Analysis Program (ETAP) with all the four (4) 11 kV feeders and their associated outdoor substations in composite form are shown in Figure 2.1. The Ugbowo injection substation gets its electricity supply from Oluku 33 kV feeder. The Oluku indoor 33 kV feeder control panels have two Incomers called Incomer 1 and Incomer 2 which control and distribute electricity to the Ugbowo 2x15 MVA, 33/11 kV distribution network. The Ugbowo 2x15 MVA, 33/11 kV distribution network in turn have four (4) 11 kV feeder; two (2) each connected to Incomer 1 and Incomer 2 with 15 MVA, 33/11 kV power transformer each. Incomer 1 have two (2) 11 kV feeder which are FGGC 11 kV feeder and Uselu 11 kV feeder; while Incomer 2 have two (2) 11 kV feeder which are Eguaedaiken 11 kV feeder and Ugbowo 11 kV feeder. The Oluku 33 kV feeder which feeds the Ugbowo 2x15 MVA, 33/11 kV electric power distribution network gets its electricity supply from Ihovbor Power Station, Ihovbor, Benin City, Nigeria. The Ihovbor Power Station is a National Integrated Power Project (NIPP) built to cater for insufficient power in the country.

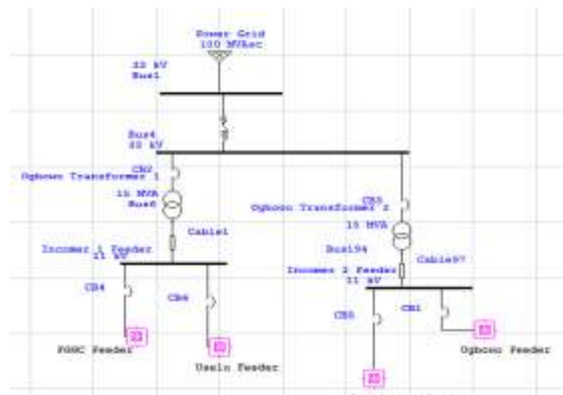

Figure 2.1: Single Line Diagram of Ugbowo 2x15 MVA, 33/11 kV Electric Power Distribution Network Model in ETAP

2.2 Brief Description of Load Point Indices (LPI)

Power supply is delivered to each customer load points starting from a substation through distribution network [11]. The Load Point Indices (LPI) make use of the reliability indices, which is a statistical tool that is deployed to evaluate the performance of electrical network. The reliability of a power system is usually measured in terms of several indices [12]. They are divided into load point indices and generalized reliability indices. Load point reliability indices are evaluated at each load point of the bus bar system and are assessed using failure rate outage time/repair duration and the average annual outage time [12]. The LPI is an essential metrics for evaluating electrical distribution networks where consumer's points (Load Points) are assessed and evaluated to know the performance of the network under review.

The LPI is a reliability Indices (RI) that makes use of classical concepts which are three primary indices tool such as failure rate, average outage duration and average annual outage. But to reflect the severity or significance [13] of the system outage at the load point, additional reliability indices called the customer-orientated indices are needed. These include SAIFI, SAIDI, CAIFI, ASAI and ASUI, which reflect customer or load point.

2.3 Performance Indices

Performance indices (PI) are essential metrics for evaluating the distribution network or system performance. These performance indices are majorly reliability metrics which are statistical tool used to analyze data of a well-designed set of loads, component, system or customers' satisfaction. Most reliability characteristic of component, feeder or entire system are determined by their functionality using historical data. Power companies usually make use of two reliability metrics which are frequency and duration to estimate the performance of their systems or components. The following briefly describes some of the performance indices of a system:

2.3.1 Failure Rate (λ)

This is defined as the basic index of reliability which measure the frequency at which fault occurs in the system.

$$\lambda = \frac{Frequency\ of\ Outage/year\ or\ month}{Total\ Hours\ of\ Available/year\ or\ month} \quad (1)$$

2.3.2 Mean Time to Failure $(MTTF)$

This is a reliability metrics that defined the function of non-repairable equipment in a given system.

$$MTTF = \frac{1}{\lambda} \quad (2)$$

2.3.3 Mean Time to Repair or Recovery $(MTTR)$

This is the average time needed to repair a faulty system or component and bring it back to its full operating state.

$$MTTR = \frac{Total\ System\ Downtime}{Number\ of\ Outage} = \frac{1}{\mu} \quad (3)$$

2.3.4 Mean Time between Failure $(MTBF)$

It is the average time interval between consecutive failures of a repairable system or component.

$$MTBF = \frac{Total\ System\ Operating\ Hours}{Number\ of\ Outage} = MTTF + MTTR \quad (4)$$

2.3.5 Availability (A)

This is the probability that an equipment or system will be available to perform the desired function when needed.

$$A = \frac{Uptime}{Expected\ Uptime} = \frac{\mu}{\lambda + \mu} = \frac{MTBF - MTTR}{MTBF} = \frac{MTTF}{MTTF + MTTR} \quad (5)$$

2.3.6 Unavailability (U)

This is the average time interval in which a system or component is not available to perform the required function.

$$(U) = \frac{MTTR}{MTTF + MTTR} = 1 - \frac{MTTF}{MTTF + MTTR} = 1 - A \quad (6)$$

2.3.7 Reliability (R)

This is the probability that a system or device perform a function correctly when needed to do so.

$$R = e^{-\lambda t} \quad (7)$$

Where, $\lambda = failure\ rate, t = time\ of\ outage$

2.3.8 System Average Interruption Frequency Index $(SAIFI)$:

This is the measurement of how many sustained interruptions for an average consumer will experience during the period of a year.

$$SAIFI = \frac{Frequency\ of\ Outage}{Number\ of\ Customer\ Served} \quad (8)$$

2.3.9 System Average Interruption Duration Index $(SAIDI)$

This defines the measurement of how many interruption hours an average customer will experience during the period of a year.

$$SAIDI = \frac{Total\ Outage\ Duration\ in\ Hours}{Number\ of\ Customer\ Served} \quad (9)$$

2.3.10 Average Service Availability Index $(ASAI)$

This defines the measure of the average availability of the distribution network services to customers.

$$ASAI = \frac{Customer\ Hours\ of\ Available\ Service}{Customer\ Hours\ Demanded} \quad (10)$$

2.3.11 Average Service Unavailability Index $(ASUI)$

This defines the measure of the average unavailability of the distribution system services to customers.

$$ASUI = \frac{Customer\ Hours\ of\ Unavailable\ Service}{Customer\ Hours\ Demanded} = 1 - ASAI \quad (11)$$

3. Results and Discussion

This section of the research work deals with the results presentation and discussion.

3.1 Results

This subsection presents the results obtained from the tripping profile of the 33kV feeder of Ugbowo 2x15 MVA, 33/11 kV injection substation. The results involve reliability indices and performance indices of the 33kV feeder and the results discussion are carried out in the subsequent subsection of the work.

Figure 3.1: Monthly Failure Profile of 33 kV Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

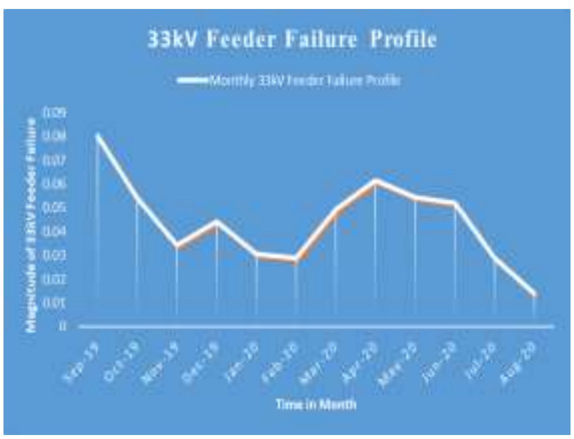

Figure 3.2: Monthly Failure Profile of 33 kV Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

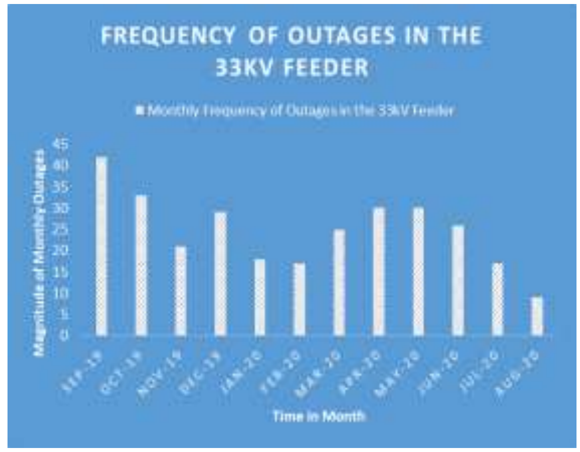

Figure 3.3: Monthly Outages of 33 kV Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

Figure 3.4: Monthly Mean Time to Recovery of the 33 kV Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation

Table 3.1: Monthly Reliability Indices of the 33kV Feeder for the Month of Sept. 2019 to Aug. 2020

Months Index	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	June 2020	July 2020	Aug. 2020	Sept. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Failure Rate (λ)	0.0307	0.0290	0.0493	0.0615	0.0544	0.0519	0.0290	0.0138	0.0802	0.0542	0.0343	0.0443
MTTR	8.8044	6.4124	9.4952	7.7497	6.4347	8.4373	9.25	10.1489	4.6781	4.1089	5.1105	3.0845
MTTF	32.5732	34.4828	20.2840	16.2601	18.3823	19.2678	34.4828	72.4638	12.4688	18.4502	29.1545	22.5734
MTBF	41.3776	43.978	29.7792	24.0097	24.817	27.7051	43.7328	82.6127	17.1469	22.5591	34.265	25.6579
Availability	0.7872	0.7841	0.6811	0.6772	0.7407	0.6955	0.7885	0.8820	0.7271	0.8178	0.8509	0.8798
Unavailability	0.2128	0.2159	0.3189	0.3228	0.2593	0.3045	0.2115	0.118	0.2729	0.1822	0.1491	0.1202

Table 3.2: Annul Reliability Indices of the 33kV Feeder for the Month of Sept. 2019 to Aug. 2020

Index	Failure Rate (λ)	MTTR	MTTF	MTBF	Availability (A)	Unavailability (U)
Value	0.0432	6.5203	23.148	29.6684	0.7802	0.2198

Table 3.3: Monthly Tripping Profile of the 33kV Feeder for the Month of Sept. 2019 to Aug. 2020

Months Index	Jan.2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	June 2020	July 2020	Aug. 2020	Sept. 2020	Oct. 2020	Nov. 2020	Dec. 2020
SAIFI	0.0022	0.0021	0.0031	0.0036	0.0036	0.0031	0.0021	0.0011	0.0051	0.0040	0.0025	0.0035
SAIDI	0.0192	0.0132	0.0287	0.0281	0.0234	0.0266	0.0190	0.0111	0.0238	0.0164	0.0130	0.0108
ASAI	0.7870	0.8434	0.6809	0.6771	0.7405	0.6953	0.7886	0.8772	0.7271	0.8178	0.8509	0.8798
ASUI	0.213	0.1566	0.3191	0.3229	0.2595	0.3047	0.2114	0.1228	0.2729	0.1822	0.1491	0.1202

Table 3.4: Annual Tripping Profile of the 33kV Feeder for the Month of Sept. 2019 to Aug. 2020

Index	Value
SAIFI	0.0358 interruptions / customer / yr
SAIDI	0.2336 h / customer /yr
ASAI	0.7803
ASUI	0.2197

Figure 3.5: Monthly Mean Time to Failure of the 33 kV Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

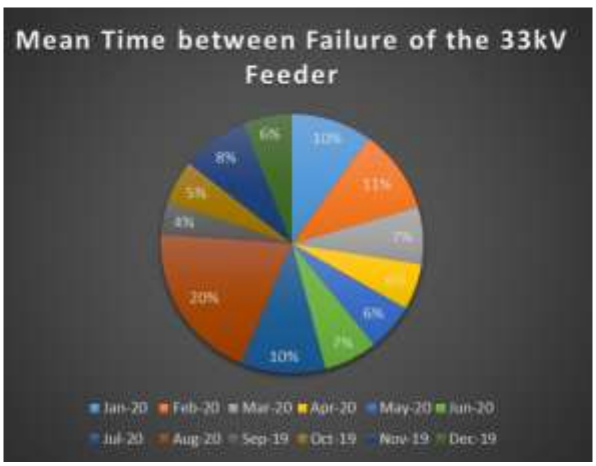

Figure 3.6: Monthly Mean Time between Failure of the 33 kV Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

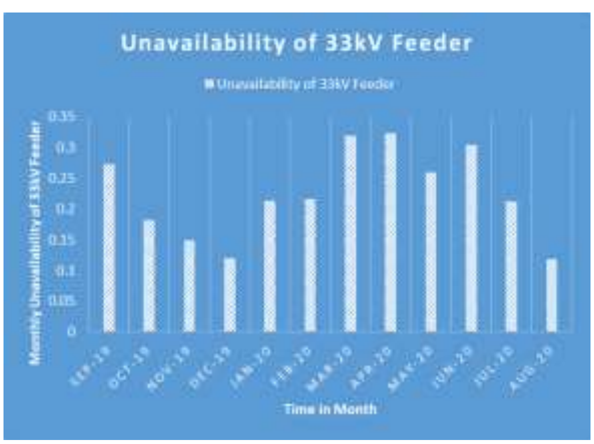

Figure 3.7: Monthly Unavailability of 33 kV Feeder of Ugbowo 2 x 15 MVA, 33/11 kV Injection Substation.

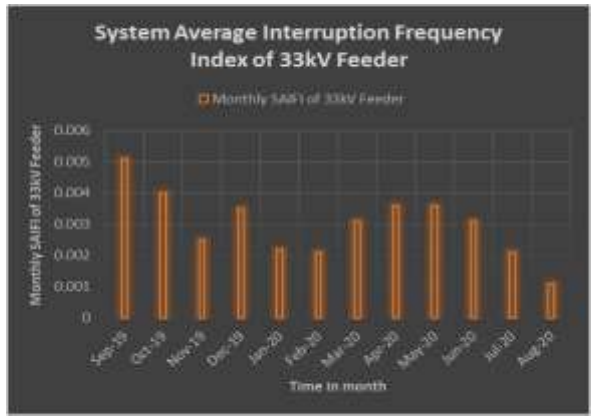

Figure 3.8: Monthly System Average Interruption Frequency Index of the 33 kV of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

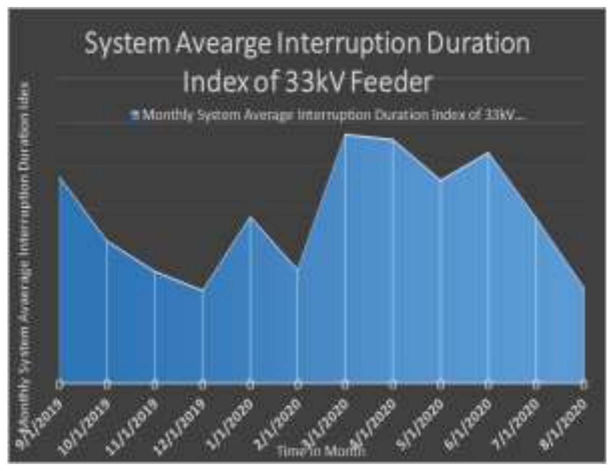

Figure 3.9: Monthly System Average Interruption Duration Index of the 33 kV of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

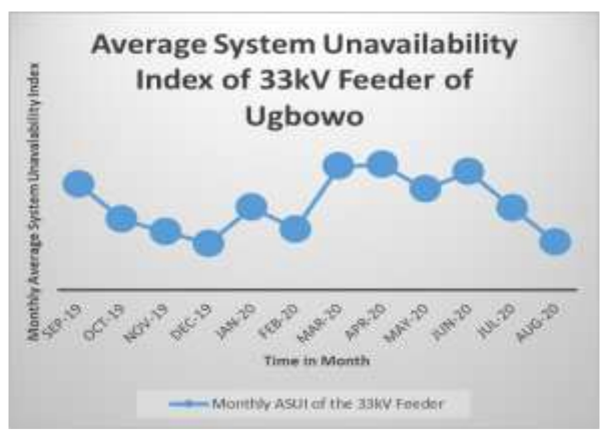

Figure 3.10: Monthly Average System Unavailability Index of the 33 kV of Ugbowo 2x15 MVA, 33/11 kV Injection Substation.

3.2 Discussion

The performance indices of the 33 kV feeder of Ugbowo 2x15 MVA, 33/11 kV electric power distribution network has been determined and the results of its tripping profile interpreted graphically using the Microsoft Excel is presented.

Table 3.1 presented the monthly reliability indices of the 33 kV feeder with row one (1) of the Table 3.1 showing the results of the monthly failure rate of the 33 kV feeder with the month of September 2019 having the highest failure rate of 8.0%; this is as a result of prolong downtime witnessed in the month. This is followed by the month of April 2020 (6.15%), May 2020 (5.44%), October 2020, (5.42%), etc. While February 2020 had the least failure rate of 2.9%. Figure 3.1 and Figure 3.2 showed the graphical representation of the 33 kV feeder. These Figures (3.1 & 3.2) showed the rate of tripping for the period under study.

Figure 3.3 shows the monthly outage frequency of the 33 kV feeder of the Ugbowo 2x15 MVA, 33/11 kV injection substation per year. The mean time to repair or recover (MTTR) of the 33 kV feeder is shown in row two (2) of Table 3.1 with the month of August 2020 having the highest MTTR (10.148 h), which indicates a prolonged downtime in the network. The least MTTR was recorded for the month of December 2019 (3.084 h). The graphical interpretation of the MTTR of the feeder is shown in Figure 3.4. Also, row three (3), four (4), five (5) and six (6) of Table 3.1 showed the mean time to failure (MTTF), mean time between failure (MTBF), availability (A) and unavailability (U) of the 33 kV feeder of the Ugbowo 2x15 MVA, 33/11 kV injection substation. The month of September 2019 had the least MTTF value while August 2020 had the highest value. Figure 3.5 shows the graphical representation of the MTTF for period under study.

Figure 3.6 shows the mean time between failure of the 33 kV feeder with the month of September 2019 having the least time of 17.146 h while August 2020 had the highest (82.612 h); this difference is as a result of improve ways of repair/replacement of faulty components and better preventive maintenance (PM) method. The monthly unavailability of the feeder result (Figure 3.7) indicates that April 2020 had the highest unavailability of 32.28% while August had the least (11.8%). It is worth noting that Table 3.2 shows the annual reliability indices, annual unavailability (21.98%), annual failure rate (4.32%), annual MTTR (6.520h), MTTF (23.148 h), MTBF (29.668 h) and availability (78.02%) of the 33 kV feeder.

The monthly tripping profile of 33 kV feeder is shown in Table 3.3 with the system average interruption frequency index (SAIFI) in row one (1). SAIFI had the lowest value in the month of August 2020 (0.011 interruptions/customer/month) while the highest was recorded in the month of September 2019 (0.0051 interruptions/customer/month). The monthly graphical representation of the tripping profile of 33 kV feeder is shown in Figure 3.8. The system average interruption duration index (SAIDI) was presented in Table 3.2 row two (2). SAIDI had the lowest value of 0.0111 h/customer/month in the month of August 2020 and highest value of 0.0287 h/customer/month in April 2020. Figure 3.9 shows the graphical representation of SAIDI of the 33 kV feeder. Also, row three (3) and four (4) of Table 3.2 showed the average system availability index (ASAI) and the average system unavailability index (ASUI) respectively. The ASAI was highest (87.98%) in the month of December 2019 and the lowest (67.71%) in the month of April 2020. While the ASUI was lowest (12.02%) in the month of December 2019 and highest (32.29%) in the month of April 2020. The representation of the monthly ASUI results graphically is given by Figure 3.10.

Table 3.4 presented the annual tripping profile of the 33 kV feeder of the Ugbowo 2x15 MVA, 33/11 kV injection substation with SAIFI of 0.0358 interruptions/customer/yr, SAIDI of 0.2336 h/customer/yr, ASAI of 78.03% and ASUI of 21.97% which is a far cry from the recommended international acceptable standard values (IASV) of 0.01 interruptions/customer/yr for SAIFI and 99.99% for ASAI. But it was observed that the SAIDI falls within the recommended international acceptable standard value (IASV) of 2.5 h/customer/yr.

Some of the obvious causes of the frequent tripping of the 33 kV feeder were highlighted as serious flashover and arcing on the outdoor breakers, isolator of the University of Benin (UNIBEN) 5 MVA power transformer, open circuit of the red phase and earth faults of the UNIBEN 5 MVA power transformer which flagged on open circuit of the blue and red phase, and inter-tripped Oluku 33 kV feeder, phase imbalance fault, system collapse, cut of jumper at the main isolator, broken pole, hot spot fault at transmission station, etc. Planning for routine and preventive maintenance will reduce the 33 kV feeder tripping and also the continuous maintenance and regular clearing of grasses in the Right of Way (ROW) of the 33 kV feeder will go a long way in reducing the tripping of the feeder. Hence, we urge the utility authorities to do more and be proactive in preventive maintenance instead of reactive maintenance in bringing the SAIFI and ASAI values to acceptable values of the recommended IASV. In other words, there is need to act swiftly to reduce the indices values of the 33 kV feeder to meet the international acceptable standard value.

4. Conclusion

The outcomes of this study have shown that the tripping profile of the 33 kV feeder of the Ugbowo 2 x 15 MVA, 33/11 kV injection substation is worrisome with the evidence that the performance indices are not within the international acceptable standard value (IASV) as it is today. The concerned authorities have to put in more effort to curb the unacceptable values of the 33 kV feeder performance indices, since the procedure explained in this article is essential in finding out feeder tripping profiles in the power network, in order to schedule for routine and preventive maintenance of the system.

The degree of reliability of power supply is measured by the frequency, duration and magnitude of disturbances to the electricity supply [14]. Identifying the tripping profile of feeders in the distribution and transmission networks will help for effective scheduling of maintenance and also quick fault clearing along the feeder thereby reducing the frequency of electricity supply interruptions and downtime in the network.

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